THE

JOURNAL OF GEOLOGY

JULY–AUGUST, 1898

THE ULTERIOR BASIS OF TIME DIVISIONS AND THE CLASSIFICATION OF GEOLOGIC HISTORY.

It was intimated in the introduction to the symposium on the classification and nomenclature of geologic time divisions published in the last number of this magazine that the ulterior basis of classification and nomenclature must be dependent on the existence or absence of natural divisions resulting from simultaneous phases of action of world-wide extent. If there have been such universal phases and if they can be detected, they must ultimately be accepted not only as the true basis of division, classification and nomenclature, but their exposition must constitute the major work of research and of instruction. The most vital problem before the general geologist today is the question whether the earth's history is naturally divided into periodic phases of world-wide prevalence, or whether it is but an aggregation of local events dependent upon local conditions uncontrolled by overmastering agencies of universal dominance.

That there were no universal breaks in sedimentation or in the fundamental continuity of life is not only admitted but affirmed without hesitation. The old doctrine of physical cataclysms attended by universal destruction of life has passed beyond serious consideration. And so, in the judgment of the writer, have all doctrines which attribute profound effects on the life of the globe or the progress of sedimentation to the violence of physical disturbances of any kind. That sedimentation has

been in constant progress somewhere since the inauguration of the pre-Cambrian lands and seas, and that life has been likewise continuous and self-derivative, may be accepted as fundamental postulates. If, therefore, we seek for *absolute* divisions we doubtless seek in vain. But this does not dismiss the question whether this continuity of physical and vital action proceeded by heterogeneous impulses or by correlated pulsations. If the latter, then the history of the earth, when deciphered, will assume a rhythmical periodicity susceptible of natural classification and of significant and rational nomenclature; if the former, the contradictory phases of local actions will inhibit all but the most general unity and render classification and nomenclature either arbitrary or provincial.

I venture to urge three general grounds upon which I entertain the former view. These grounds, if valid, hold out the hope that the history of the earth will be found not only susceptible to natural division, but capable of its truest exposition only through the recognition of its inherent periods.

I. The first of these grounds is the presumption that great earth movements affect all quarters of the globe. Minor stresses may find relief in local readjustment, but profound stresses cannot be relieved, it is assumed, without generating appreciable stresses in other portions of the globe and leading to general readjustment. In a globe, all of whose parts owe their positions to the stress and tension of other parts, every rearrangement that rises in magnitude above the limits of local support extends its influence to the whole. Any massive earth movement must change the gravitative stresses of all parts of the globe unless the movement be divided into contrary phases so adjusted as to be compensatory, the possibility of which in the strict sense may be questioned. The recognized causes of profound movements such as secular refrigeration, change of speed of rotation, progressive molecular rearrangement, and like agencies, are comprehensive in their action and accumulate general stresses whose natural issue is coöperation in a common movement of relief.

The validity of this presumption of general coöperative movements will perhaps not be so much questioned as the mode of their execution. There are those who believe that a downward movement in one region is correlated with an upward movement in some other region. The correlated movements have, therefore, opposite phases and if the distribution of these is not controlled by some unifying agency the general terrestrial effects are heterogeneous, or, if not that, at least uncertain. This view is the natural sequence of the doctrine of a thin, floating crust warping to satisfy its own changes of density and tension, and wrinkling to adapt itself to a shrinking nucleus. Accepting the truth that lies under this view, but rising to a broader generalization, there are those who entertain the conception that the depressions of the earth's surface habitually became more depressed with every readjustment to smaller dimensions (local exceptions aside), while the protuberances became more protuberant. In other words, the oceanic basins became progressively deeper and more capacious, while the continents became higher (degradation aside). In this assumption of habitual downward movements of the ocean bottoms and of correlative upward movements of the continents, there lies, if it be true, a basis for the natural division of geologic events, these movements being in themselves and in their immediate consequences the basis of such division. The full establishment or overthrow of this assumption must await the extension of critical research to at least the major part of the earth, and it is not the purpose of this paper to seriously attempt its advocacy by the citation of the evidence already gathered in its support. Incidentally it will be touched upon in the discussion following.

II. The second ground of belief in a fundamental periodicity in terrestrial progress is founded on the conviction that the major movements of the earth's surface have consisted of the sinking of the ocean bottoms and the withdrawal of additional waters into the basins whose capacities were thereby increased. This belief is not quite identical with the assumption last made, for it does not necessarily involve the simultaneous action of

the different ocean beds, although the conclusions about to be urged would be strengthened if such common action could be demonstrated. But quite apart from this, it is believed the following argument rests upon rather firm observational and inductive grounds except in the matter of two fundamental postulates which are almost universally assumed by geologists. These are as follows: (1) It is assumed that the earth was at first a nearly perfect spheroid, the surface being essentially plane. (2) It is assumed that the great movements of the earth's crust have consisted fundamentally of shrinkage. Probably no serious geologist maintains that the earth has enlarged its average diameter during geological history by expansive action, whatever he may hold respecting local expansion.

These two propositions being accepted, it follows that the radial shrinkage of the ocean bottoms has surpassed the radial shrinkage of the continental platforms to the average amount of some 10,000 or 12,000 feet. This excess of radial shrinkage is to be multiplied by four to measure the excess of volumetric shrinkage, since the area of the ocean bottoms is about four times the area of the continental platforms. The master factor, therefore, in the surface movements of the earth has been the sinking of the ocean bottoms and the formation of the great oceanic basins. Most geologists will probably agree that the continental platforms have also sunk, in the sense that they have shortened their radial distances from the center of the earth. Opinion seems to be divided, however, on the question whether there have been actual epeirogenic uplifts or not. Probably most geologists would regard the rising of the Thibetan plateau in late Tertiary times as involving an actual increase of radial distance. Probably very few geologists would question the absolute elevation of the crests of the loftier mountain ranges. However, the question of absolute as distinguished from relative sinking does not seriously affect the question in hand. If the earth has absolutely grown smaller by some notable amount the average ideal ocean has, as a consequence, grown deeper (if its volume has remained constant), for its circumferential expanse

has been reduced. Aside from this, so far as I can see, our argument holds as firmly for relative as for absolute sinking.

From the greater depths to which the ocean bottoms have sunk, the presumption follows that in every great crustal readjustment the major factor consisted of the descent of the ocean bottom or some part of it. Logically, as here stated, this is only a presumption which might be set aside by the assumption of a single or a few great depressions, while the other movements might be upward or indifferent, but this will appear less tenable in the light of further considerations.

Not only has there been increase in depth, but increase in capacity also. From a capacity essentially zero at the outset the basins have developed a capacity sufficient to hold nearly all the water of the globe. In the aggregate, therefore, the capacities of the ocean basins, as well as their depths, have been increased by crustal readjustment, and the presumption is that this has usually been the case in individual readjustments, although this does not rigorously follow. It will be sustained, however, by further considerations. The crustal readjustments here referred to are those resulting from internal causes. External readjustments work to precisely opposite ends, the degradation of the land and the filling of the basins. This opposing action strengthens the presumption that the internal causes have habitually increased the capacity of the basins, for they have grown more and more capacious in spite of this constantly opposing action. This constant filling in affords a presumption of frequently repeated increases of capacity; otherwise the land should have disappeared.

Proceeding upon the presumption that internal readjustments habitually increased the capacity of the ocean basins, it is important to note in detail the consequences that follow. These are involved in the functions of the circumcontinental terrace, and will be more easily followed after an explicit statement of these functions. These are more or less fully apprehended by all acute students of continental evolution, but like the correlative functions of baseleveling previous to the explicit exposition

of Powell, they have not come into that large service as working principles of which they are susceptible.

Every continent which stands in a given position with reference to the sea for any prolonged period develops a submarine terrace about its borders. This is formed from the débris of the land deposited beneath the edge of the sea. In its initial stages it is nothing more than the familiar shore terrace; but as it develops it becomes a broad submerged platform with a steep face dropping away to the abysmal depths of the ocean. The submerged platform has its outer limit at the depth at which detritus can be effectively moved off shore by the agitation of the surface waters. This, though varying with conditions, may be roughly taken to be one hundred fathoms. The breadth attained by the upper surface of the terrace is conditioned upon the length of time the continent remains in a fixed attitude and the activity of land wash. Simultaneously the sea cliffs are moving inland, and the valleys are developing base plains which are the correlatives of the terrace plain which is growing seaward, as illustrated in Fig. 1.

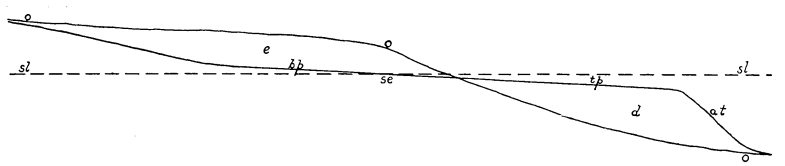

FIG. 1.—*o-o* Original surface. *s l* Sea level. *e* Land carried away by erosion. *d* Detritus built into circumcontinental terrace. *t p* Terrace plain. *a t* Abysmal terrace face. *b p* Base-plain developing landward.

The extreme limit of development is attained when the continent has been baseleveled and no farther detritus is furnished for the extension of the terrace. The baselevel of the continent then becomes essentially continuous with the submerged terrace surface, and the whole constitutes the perfected continental platform, as shown in Fig. 2.

The development of the circumcontinental terrace and of the perfected continental platform is subject to intercurrent disturb-

ances from local and from general sources. There appear to be two systematic sources of slight but very critical modification that require special consideration.

FIG. 2.—*b p* Continental base-plain. *s l* Sea level. *t p* Submerged terrace plain. *a t* Abysmal terrace face.

1. The transfer of débris from the land to the sea displaces an equivalent amount of water, and raises the sea level proportionately, and causes an advance upon the land. The effects are volumetrically small compared with the great body of the ocean, but a slight rise in the surface as the baselevel stages of the continent are attained is peculiarly effective. This coöperates with the cutting back of the sea cliff, and, combined, they become effective in advancing the edge of the sea upon the border of the land.

2. There are both theoretical and observational grounds for the belief that in the process of periodic readjustment of the earth to its internal stresses, portions of the crust are thrust up to heights notably above the plane of isostatic equilibrium, and that these portions gradually settle back toward equilibrium by virtue of the slow fluency or quasi-fluency of the rocks. Recent pendulum studies by Putnam and Gilbert seem to indicate that the portion of our continent most notably lifted in late Tertiary times still stands appreciably above isostatic equilibrium, and there is little doubt that the same is true of other continents, as is, indeed, indicated by partial pendulum data. There is, however, a large mass of concurrent data which shows an aggregate subsidence of the continent since late Tertiary times, data which have been industriously marshaled in the interests of an epeirogenic explanation of the glacial period. This leads to the impression that in late Tertiary times, when the upward move-

ment reached its maximum effects, the land stood very notably above isostatic equilibrium, and that it has been settling back, but has not even now reached isostatic equilibrium. While the generalization cannot be rigorously established, there seem to be sufficient data to warrant entertaining tentatively the doctrine that in periods following crustal upheavals which pass beyond the plane of equilibrium the lifted portions slowly settle back toward equilibrium. If so, this retrocession would coöperate with the filling of the basins in causing an advance of the sea upon the land. At the same time the conditions for the seaward growth of the terrace plain may still continue and the plain be thus simultaneously extended on both borders.

As already noted, the evolution of this peri-coastal plain is subject to interruptions and local modifications to an extent comparable to the interferences in the development of a base-plain, and perhaps to a greater degree, but I think it has like claims to acceptance as an effective general process.

Now the development of such submerged terraces around the several continents for any given period is accurately correlated by the sea level. They are all built immediately beneath its border at a common level. The continental baselevels are correlated by the same controlling horizon. So, necessarily, the final continental platforms are likewise reduced to the same common natural datum plane.

If, therefore, it be admitted that there are periods of general quiescence, it follows that there are periods of simultaneous platform-making just below and just above the sea level on all continents. And this is accompanied by an inevitable tendency of the sea to advance upon the land. Now this submerged sea shelf is the special zone of sedimentation, and hence it is the peculiar locus of registration of geologic events. It is at the same time the peculiar habitat of shallow-water marine life, and this is the life which specially enters into the geologic record. We know almost nothing of the ancient abysmal life and relatively little of the land life. Both the physical and the biological record, which are our chief dependence in reading the

earth's history, are therefore made upon the surface of the peripheral terrace and of its inland extension, and hence this becomes preëminently a critical geologic zone.

To follow out the sequence of a typical cycle, let it be supposed that a circumcontinental submarine platform of ample dimensions has been developed, and that it is peopled by a fauna comparable to its extent and resources. It has been suggested that a typical crust movement has for its major feature the depression of the sea bottom and an increase in the capacity of the basin. Let such a movement succeed. The effect of this, whether it involves one ocean basin or all, must be the withdrawal into itself of water from the submerged platforms of all the continents alike, since the oceans are connected. If the basin movement has sufficient magnitude to draw down the sea surface to the terrace edge, the shallow water zone becomes narrowed to a mere strip on the rapidly shelving abysmal face of the terrace, as illustrated in Fig. 3.

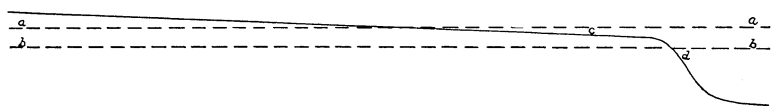

FIG. 3.—*a* Former sea level. *b* Succeeding sea level. *c* Former ample shallow-water tract. *d* Succeeding constricted shallow-water tract.

The ample fauna of the previous broader tract is thus forced into the constricted zone and brought under the direst stress of competition and scant room. The destruction of the larger part is inevitable, and the residue is forced to undergo repressive evolution to meet the severe conditions of the new environment. As this is common to all continents, it constitutes a comprehensive evolution of the severely competitive phase. There would, to be sure, be such exceptions as the local variations from the typical configuration of the continental border afford. These might be very considerable. Portions of the continents may have been previously carried down to moderate depths in the sinking of the ocean basins and may become shallow water ground by

the lowering of the sea level. But even then there would remain a community of dominant action that would give a decisive aspect to the progress of life and to the sedimentation on all continents alike.

If now a long period of quiescence follows, a new universal terrace will begin to form and will extend its marine plain seaward and its baselevel inland until at length an ample zone for the evolution of a new shallow water fauna is provided. If to the cutting of the sea edge and the filling in of the sea basin there be added the settling of the continent, the sea may make a wide incursion upon the low parts of the land, as it did in Cretaceous times, and unusual facilities be thus afforded for that form of life-evolution which follows rich and genial conditions.

Thus on the one hand the sinking sea bottom induces that form of evolution in which stress is the dominant factor, and on the other, quiescence induces that form of evolution in which new ground and rich opportunities constitute the dominant condition. Both of these follow simply and inevitably from the sinking of parts that have been already predominant in sinking, and from prolonged intervening stages of quiescence. Almost the only essential postulate of the one evolution is a periodic increase of sea basin capacity; of the other, periodic quiescence. No profound catastrophe is involved; rather on the contrary it is inhibited by the conditions postulated.

Both the evolution of restrictive environment and the evolution of expansive environment, in the opinion of the writer, are effective in the change of faunas, though their respective results may be as different as their modes. In the rhythmical action postulated there is an alternating application of these opposed evolutionary processes with the natural result of an effect of the maximum order; for the evolutionary effects of restrictive conditions are believed to reach their greatest magnitude when they follow conditions of expansion, and, reciprocally, expansive conditions realize their greatest results when they follow conditions of restriction.

Such a succession of shallow sea incursions and withdrawals

reciprocating with crustal movements and quiescence seem to me to be well indicated as the master features of geologic progress from the beginning of the Palæozoic era to the present time. To these features I look for the primary terms of a natural and permanent system of classification and nomenclature.

III. The third agency which affords some promise of becoming a means for strict correlation of transoceanic events and for the division of these events into their natural epochs is an assumed fluctuation in the constitution of the atmosphere. Too little has yet been learned by direct induction respecting the nature of the successive atmospheres of the geologic periods to render this a firm ground for conclusions, but I venture to invite attention to the doctrine enunciated some time ago[1] that the exposure of the crystalline areas to the action of the air necessarily led to changes in the constitution of the atmosphere, especially in the critical element of carbon dioxide. The principle was urged that the greater the exposure of the decomposable crystalline rocks in area and in elevation, by leading to wider contact and deeper penetration of the atmosphere and atmospheric waters, the more rapid must have been the decomposition of the crystalline rocks and the consequent consumption of carbonic acid in the carbonation of the alkalis and alkaline earths, which is the most important part of the decomposing process. This greater exposure obviously followed the crustal readjustments, for at these times the land was largest and highest. It then not only exposed the greatest surface to atmospheric contact, but the atmospheric waters penetrated deepest because of the hydrostatic pressure arising from great differences of water level. At times of approximate degradation to baselevel and of sea-border encroachment the area of action was reduced and the power of penetration of the atmospheric waters became slight because of the low elevation and consequent slight differential pressure. In a word, the consumption of the carbonic acid proceeded rapidly at times of broad and

[1] A Group of Hypotheses Bearing on Climatic Changes. JOUR. GEOL., Vol. V, No. 7, October-November 1897.

high elevation of the land, and slowly at times of low altitude, grand averages being always understood.

If the atmosphere were once excessively burdened with carbonic acid and its later history has been merely a progressive depletion, these stages of rapid consumption only introduced specially rapid reduction of the superabundant supply, and the effects on tangible geological processes may have been quite beyond detection. But if, on the other hand, the atmosphere was limited in amount at the beginning and has been gradually supplied as well as gradually consumed throughout the ages and has been susceptible to serious change, an unusually rapid consumption of the carbon dioxide at the stages of land elevation would result in appreciable depletion of the atmosphere unless the supply were correspondingly increased. On the other hand, at those stages in which the continents were reduced well toward sea level and the land areas were diminished by the incursion of the ocean, the consumption of the carbonic acid would be checked, and if the supply were not correspondingly reduced, reënrichment in carbonic acid would follow. Under this hypothesis, the history of the atmosphere involved alternate enrichment and depletion.

The carbon dioxide is critical because of that peculiar thermal capacity by virtue of which it retains the heat of the sun to a relatively extraordinary degree, a capacity which is shared by water vapor, but which is possessed in very low degree by oxygen and nitrogen. The amount of aqueous vapor, however, is dependent upon temperature, while the carbon dioxide is stable and active at all terrestrial temperatures. Whenever, therefore, there is a notable percentage of carbon dioxide in the atmosphere, it performs a most important function in conserving the heat of the sun and raising the temperature of the lower atmosphere and of the earth's surface. By this rise it increases the aqueous vapor in the atmosphere, which in turn aids the carbon dioxide in retaining the heat of the sun, the two acting conjointly. On the other hand, when the carbon dioxide is reduced to a small factor, the heat of the sun is less effectually

retained at the surface of the earth, the water vapor enters less into the atmosphere and low temperature and aridity are the consequences.

If these considerations are valid, the history of the earth has been marked by periods of relative cold and aridity resulting from stages of rapid rock disintegration, alternating with periods of warmth and moisture correlated with periods of limited rock disintegration and of carbonic acid accumulation. These stages are genetically connected with periods of continental elevation and rapid subaërial degradation, on the one hand, and with slight degradation and sea incursion, on the other. It will be observed that continental elevation as a purely topographical condition contributes to cold and aridity, while continental degradation correlated with oceanic extension contributes to equalization of temperature and to warmth. We have, therefore, the conjoint action of topographic agencies with atmospheric constitution in producing alternations of cold and aridity with warmth and moisture. The aridity is thought to express itself in salt and gypsum deposits and in the red sediments with which these are habitually associated; the cold, in glaciation; the warmth and moisture, in the polar extension of tropical life.

Now these atmospheric influences are strictly simultaneous for all parts of the globe, latitudinal effects, of course, being neglected, for the diffusion of the atmosphere is such as to render its constitution practically uniform for all parts of the globe. In so far, therefore, as atmospheric conditions of a constitutional nature affect the progress of terrestrial phenomena, they affect them universally, and if these influences are pronounced and can be identified they furnish an additional basis for the strict correlation of transoceanic action and for the division of geological history into its natural epochs.

In summation, therefore, I rest in a somewhat confident hope that under continued study adequate natural bases for the more important divisions of geologic time and for a stable and fitting nomenclature will be found (1) in simultaneous internal readjustments alternating with intervals of relative quiescence, (2)

in the periodic development and emergence of circumcontinental terraces and their critical effects on the evolution of life, and (3) in the successive depletions and enrichments of the atmosphere. For subdivisions of lower order the migration of faunas and the special features of continental development will furnish appropriate bases, and below these again, the local phases of sedimentation and faunal adaptation will afford the provincial terms of a natural classification. If this hope be well grounded, the arbitrary divisions that now vex our system may be largely eliminated.

T. C. CHAMBERLIN.